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POTENTIAL MULTIPURPOSE ADDITIVES: FLASH-EROSION SUPPRESSANT

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Erosion and simultaneous flash were measured on M30 propellant and on a series of propelling charges containing M30 and various candidate additives. The data acquired with the ARRADCOM test fixture indicated that the carbonates and bicarbonates of both potassium and ammonium performed as well or better than the standard erosion additives (TiO_2 and talc) in reducing erosion. The flash data revealed that the bicarbonates of potassium and ammonium as well as ammonium carbonate reduced flash better than either potassium nitrate or potassium sulfate. (cont)

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20. ABSTRACT (cont)

Potassium carbonate reduced flash as well as potassium nitrate and better than potassium sulfate. In addition, the ammonium salts did not contribute to the smoke.

Limited field tests were conducted in an experimental 81-mm recoilless gun. Blast overpressure was reduced by 56% because of the ammonium bicarbonate smokeless flash reduction.

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INTRODUCTION

Secondary muzzle flash and gun barrel erosion are two major problems which have plagued the military community for years.

Since bore-surface melting is a key factor in the erosion process, the hot gases of propellant combustion are the chief culprits responsible for erosion. Secondary muzzle flash is caused by the atmospheric burning of the exhausted hot gases, carbon monoxide and hydrogen, produced by the combustion of the propellant during the ballistic cycle. Therefore, both phenomena have a common causal factor--hot combustion gases.

Lower flame-temperature propellants would reduce the temperature of the combustion products but not without sacrificing the energy necessary for increased range and/or muzzle velocity requirements anticipated with present gun systems.

The inclusion of additives to the propelling charge has been the preferred prophylactic technique for reducing both flash and erosion. Unfortunately, however, no single or universal additive has been used to correct both problems.

With U.S. artillery systems, the standard erosion additives have been TiO_2 and talc dispersed in wax, while the flash reducers have been potassium sulfate or potassium nitrate either formulated in the propellant or added to the propelling charge.

In this study, the feasibility of finding an additive which can reduce significantly both flash and erosion has been addressed.

EXPERIMENTAL

In previous studies, Bracuti and Bottei (refs 1 and 2) reported erosion data obtained with a modified 200 cm^3 closed bomb which was vented with a 91.44 cm (36 in.) barrel with a 0.95 cm (0.375 in.) bore. This modification to the closed bomb (usually referred to as the vented erosion tester) is depicted in figure 1. In this study, secondary flash as well as erosion data were required, but with the 91.44 cm barrel, secondary flash was not observed. To insure the occurrence of secondary muzzle flash with unsuppressed propellant, the barrel was shortened to 22.86 cm (9 in.). With this short barrel modification of the vented erosion tester, secondary muzzle flash occurred upon each firing with unsuppressed propellant.

A pressure transducer positioned inside the 200 cm^3 chamber of the vented erosion tester was connected to a Nicolet digital oscilloscope which was calibrated to display pressure versus time. To control pressure, a stainless steel rupture disc was inserted between the barrel and a removable coaxial steel (AISI 4340) cylinder which was 2.7 cm long with a bore of 0.95 cm.

The removable steel cylinder functions as the erosion indicator. For each shot, it was cleaned and weighed before and after firing. The weight loss after each shot was used as a measure of erosivity (mg loss per shot).

The secondary muzzle flash was measured simultaneously with a silicon diode detector which reproduced the spectral response of the human eye. With this arrangement, a spectral-time trace of each shot fired was recorded on the oscilloscope. These traces revealed flash onset time from initiation, flash peak intensity and time of occurrence, flash termination time, and integrated intensity. Typical suppressed and unsuppressed flash intensity-time profiles are presented in figure 2.

In each case, the propelling charge was standardized at a loading density of 0.25 g/cm^3 by loading 50 g of M30 propellant (Radford lot 69531, web of 0.045) in a polyethylene bag. This loading density was selected to maintain an average peak pressure of 172 MPa (25,000 psi) throughout the investigation. With flash suppressed charges, 4 g of additive were placed loose in front of the bagged propelling charge. The composition and physico-chemico properties of M30 (loading density 0.25 g/cm) and its combustion products calculated with the Blake code (ref 3) are listed in table 1. Before each candidate additive was tested, flash and erosion data were obtained for unadulterated M30 propelling charges. All succeeding flash intensity values (table 2) obtained from propelling charges containing additives were normalized to a common relative intensity scale by dividing each flash intensity by the flash intensity value obtained from the unsuppressed propelling charge.

The traditional erosion additives (talc and TiO_2) and flash suppressants [potassium sulfate (K_2SO_4) and potassium nitrate (KNO_3)] were used in this study as standards against which the efficiency of the candidate additives was assessed.

Two different groups of candidate additives were examined. One group consisted solely of inorganic materials, potassium compounds which included potassium carbonate (K_2CO_3) and potassium bicarbonate ($KHCO_3$), while the other group consisted of materials containing no metallic ion. These candidates included ammonium carbonate [$(NH_4)_2CO_3$] and ammonium bicarbonate (NH_4HCO_3).

The ammonium bicarbonate additive was also field tested in an experimental lightweight recoilless gun (LWRG) developed at ARRADCOM.* LWRG is a portable, lightweight, shoulder mounted, 81-mm fiberglass launcher which fires a SMAW warhead at a muzzle velocity of 244 m/s (800 ft/s) with an effective range of 200 m (650 ft). The standard propelling charge employs 453.6 g (1 lb) of the double base propellant NOS-IE-AA-15. The chemical composition and combustion product analysis are provided in table 3.

Blast overpressure measurements were made with pencil gauges on test firings with standard propelling charges and with charges using 36.29 g of NN_4HCO_3 (1.3 oz) packed between the propellant and the SMAW warhead.

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* This system was developed by W. Moscatiello, Munitions Systems Division, ARRADCOM.

RESULTS

Typical light intensity versus time curves for 50 g of unsuppressed and flash suppressed M30 propellant are presented in figure 2. In both cases, the secondary flash phenomenon reached maximum intensity within 6 ms and ended within 10 ms from initiation of the event. Flash started in less than 1 ms with unsuppressed propellant and was delayed by 2 ms when the suppressant was added to the propellant.

Blake code (ref 3) calculations (table 1) indicate that 50 g of M30 propellant, which is also used in the M203 propelling charge, produces a fuel gas mixture containing 0.0595 moles of CO and 0.250 moles of N_2 during the ballistic cycle. The oxidation chain reaction mechanism for the burning of hydrogen and carbon monoxide in air proceeds according to the reactions

$$H_2 + O \rightarrow OH + H$$

$$O_2 + H \rightarrow OH + O$$

$$H_2 + OH \rightarrow H_2O + H$$

$$CO + OH \rightarrow CO_2 + H$$

These reactions suggest the following several ways in which flash theoretically could be reduced:

1. Remove the oxidizer (air)
2. Eliminate CO and H_2 from combustion products
3. Lower temperature of the gases
4. React fuel gases in an alternate manner

Only the latter technique was addressed by the addition of flash suppressants to the propelling charge.

Experimental flash and erosion data are presented in table 2. The traditional wear additives, TiO_2 and talc, reduced the erosion level to 7 mg/shot and 18 mg/shot, respectively, but simultaneous flash evaluations indicated that they did not improve the secondary muzzle flash of the M30 propellant. Visual observations confirmed that these wear additives increased the smoke generated by the M30 propellant.

The standard potassium-salt flash suppressants, K_2SO4 and KNO_3, yielded lower flash values of 80 and 46 with lower erosion levels of 17 and 28 mg/shot, respectively. Potassium carbonate (K_2CO_3) and potassium bicarbonate ($KHCO_3$) reduced flash levels to 46 and 1 with erosion levels of 6 and 4 mg/shot respectively. The smoke level of the M30 propellant with the potassium salts was always higher than with the M30 alone.

It is evident from the data that the potassium salt with the highest potassium concentration is not necessarily the best flash suppressant. If potassium concentration were the sole criterion for flash suppression, $KHCO_3$ and KNO_3 with comparable potassium concentrations would rank last in this series while K_2CO_3 would rank first, but this is not the case. Since KNO_3 decomposes at 673 K (400°C), this suggests that more gaseous species are available during the ballistic cycle for effective flash suppression than is available with more thermally stable K_2SO_4 which boils at 1962 K (1689°C). Furthermore, it has been suggested by several investigators that to be effective the suppressant must be present in the gaseous state and that with potassium salts the actual effective specie is gaseous potassium hydroxide rather than gaseous potassium. The latter terminates the oxidation chain by scavenging H or OH to form H_2O according to the reactions (refs 4 and 5).

$$KOH_{(g)} + H \rightarrow K_{(g)} + H_2O$$

$$KOH_{(g)} + OH \rightarrow KO_{(g)} + H_2O$$

with the former reaction being the more important.

Ammonium carbonate reduced the flash level to 17 and the erosion level to 6 mg/shot while ammonium bicarbonate reduced the flash to 11 and the erosion level to 3 mg/shot. No increases in smoke levels were detected.

The results of the test firings of the LWRG are presented in table 4. With 453.6 g (1 lb) of NOS-IA-AA-15 propellant as the propelling charge, the blast overpressure value was 0.021 MPa (3.0 psi). Visual observations confirmed the presence of a large fireball or secondary muzzle flash which contributed to the blast overpressure. The combustion of 453.6 g of this propellant during the ballistic cycle produces 6.65 moles of CO and 1.52 moles of H_2 (table 3) that are available for burning in air to produce secondary muzzle flash. To eliminate the contribution of flash-to-blast overpressure, an additive was sought which would effectively reduce the flash without contributing additional smoke. Ammonium bicarbonate fulfilled these requirements in the laboratory device.

The addition of 36.3 g (1.28 oz) of ammonium bicarbonate to the propelling charge reduced the secondary flash and lowered the blast overpressure level (table 4) to 0.0896 MPa (1.3 psi). The 56% reduction in blast overpressure in this system, illustrates the importance of reducing the flash in other systems with marginally acceptable blast overpressure levels.

No erosion measurements were made on the disposable LWRG barrel since it is discarded after each shot.

In descending order of efficacy the ranking of the additives for both flash and erosion reduction (without regard to smoke generation) is as follows: $KHCO_3 > NH_4HCO_3 > (NH_4)_2CO_3 > K_2CO_3 > KNO_3 > K_2SO_4$.

The bicarbonates and carbonates seem to lower both the secondary muzzle flash and gun barrel erosion most effectively in the ARRADCOM test device, but the mechanisms for these processes are not obvious.

Despite the fact that the chemical composition of either M30/$KHCO_3$ or M30/K_2CO_3 combustion process is presently unknown, it may be possible to postulate why $KHCO_3$ is superior to K_2CO_3 as a flash suppressant assuming that:

1. The suppressant does not substantially react or participate in the chamber combustion process

2. Gun Tube temperature far exceeds thermal decomposition temperature

3. Thermal decomposition is completed before or in the vicinity of the muzzle

4. Potassium hydroxide KOH is the specie responsible for flash suppression

The thermal decomposition temperature of $KHCO_3$ is probably low enough to allow the thermal pulse of the ballistic cycle to completely decompose the salt into gaseous KOH and CO_2 before it reaches the vicinity of the muzzle

$$KHCO_3 \xrightarrow[\Delta]{} KOH_{(g)} + CO_2$$

in which gaseous KOH efficiently inhibits flash by scavenging H and, to a much lesser degree, OH according to the reactions

$$KOH_{(g)} + H \rightarrow K_{(g)} + H_2O$$

$$KOH_{(g)} + OH \rightarrow KO_{(g)} + H_2O$$

Potassium carbonate on the other hand is thermally more stable than $KHCO_3$ and decomposes at a significantly higher temperature (1173 K). This lowers the probability of complete thermal decomposition of K_2CO_3 within the limits of the ballistic cycle resulting in potentially less active specie available for chemical suppression of flash. The thermal decomposition products are K_2O and CO_2:

$$K_2CO_3 \xrightarrow[\Delta]{} K_2O_{(g)} + CO_2$$

In this case for flash suppression to occur K_2O has to react with water

$$K_2O_{(g)} + H_2O \rightarrow 2KOH_{(g)}$$

to form the required gaseous KOH species. This means that $KHCO_3$ supplies more immediately available gaseous KOH for flame suppression than does an equal quantity of K_2CO_3.

The erosion reduction mechanism of particulate additives such as TiO_2 is still not completely understood, but it is felt that the additive particles somehow interfere with the transfer of heat to the barrel wall. On this basis, it seems probable that the decomposition products of these salts also interfere with the heat transfer process but by some entirely different mechanism.

CONCLUSIONS

The preliminary data obtained in this investigation suggest that both ammonium bicarbonate and potassium bicarbonate have potential as universal propelling charge additives capable of reducing both muzzle flash and barrel erosion.

REFERENCES

1. A. J. Bracuti, L. Bottei, J. A. Lannon, and D. Bhat, "Erosion Resistance Evaluations of Potential Gun Barrel Coatings," Journal of Ballistics, vol 5, no. 2, 1981.

2. A. J. Bracuti, L. Bottei, J. A. Lannon, and L. H. Caveny, "Evaluation of Propellant Erosivity with Vented Erosion Apparatus," Journal of Ballistics, vol 5, no. 2, 1981.

3. E. Freedman, "A Brief User's Guide for the Blake Program," Interim Memorandum Report No. 249, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, 1974.

4. R. Freidman and J. B. Levy, "Inhibition of Opposed-Jet Methane-Air Diffusion Flames. The Effect of Alkali Metal Vapors and Organic Halides," Combustion and Flame, pp 7, 195, 1963.

5. E. T. McHale, "Chemical Suppression of Secondary Muzzle Flash," Proceedings of 14th JANNAF Combustion Meeting, pp 15-19, 1977.

Table 1. M30 composition and physico-chemico properties

Component	Composition (%)
Nitrocelloluse (12.6%)	28.00
Nitroglycerin	22.50
Nitroguanidine	47.70
Ethyl-centralite	1.50
Graphite	1.10
Cryolite	0.30
Ethanol (residual)	0.30
Water (residual)	0.00
Properties*	
T_f(K)	2990.0
C_p J/mol-K	43.9
I J/mol-K	1072.0
CO (mol/kg)	11.9
H_2	5.8
H_2O	10.4
N_2	11.9
CO_2	3.0
Total (mol/kg)	43.1
Mω (g/g-mol)	22.3
HEX_{obs} Cal/g	974.0

* Calculated by Blake Internal Ballistic Code.

Table 2. Flash and erosion data

Additive	$[C^+]$ (moles/g)	$[A^-]$ (moles/g)	Boiling point (K)	Flash (I/I_o)	Erosivity (mg/shot)	Smoke
None	-----	-----	-----	100	38	Yes
Talc	-----	-----	-----	100	18	Yes
TiO_2	-----	-----	-----	100	7	Yes
K_2SO_4	0.575	0.288	1962	80	17	Yes
KNO_3	0.496	0.496	673*	46	28	Yes
K_2CO_3	0.725	0.362	1173*	46	6	Yes
$KHCO_3$	0.500	0.500	313*	1	4	Yes
NH_4NCO_3	0.633	0.633	373*	11	8	No
$(NH_4)_2CO_3$	1.042	0.521	331*	17	6	No

* Decomposes

Table 3. NOS-IH-AA-15 composition and physico-chemico properties

Component	Composition (%)
Nitrocellulose (12.6%N)	49.0
Nitroglycerin	42.0
2-Nitrodiphenylamine	2.0
Di-normal propyl adipate	1.5
Normal lead beta-resorcylate	2.5
Monobasic cupric beta-resorcylate	2.5
Carbon black	0.5
Properties	
T_f(K)	3480.0
CO (mole/kg)	14.66
H_2	3.34
H_2O	9.54
N_2	5.03
CO_2	5.50
OH	0.47
H	0.39
NO	0.08
HEX_{obs} cal/g	1100.0

Table 4. Blast overpressure data for lightweight recoilless gun and their standard deviations

Charge weight[a] (g)	Suppressant weight[b] (g)	Blast overpressure DB	psi	MPa
453.6	0	180(1)	3.0(3)	0.021(2)
453.6	36.3	173(1)	1.3(3)	0.010(2)

[a] NOS-IA-AA-15 propellant.

[b] Ammonium bicarbonate.

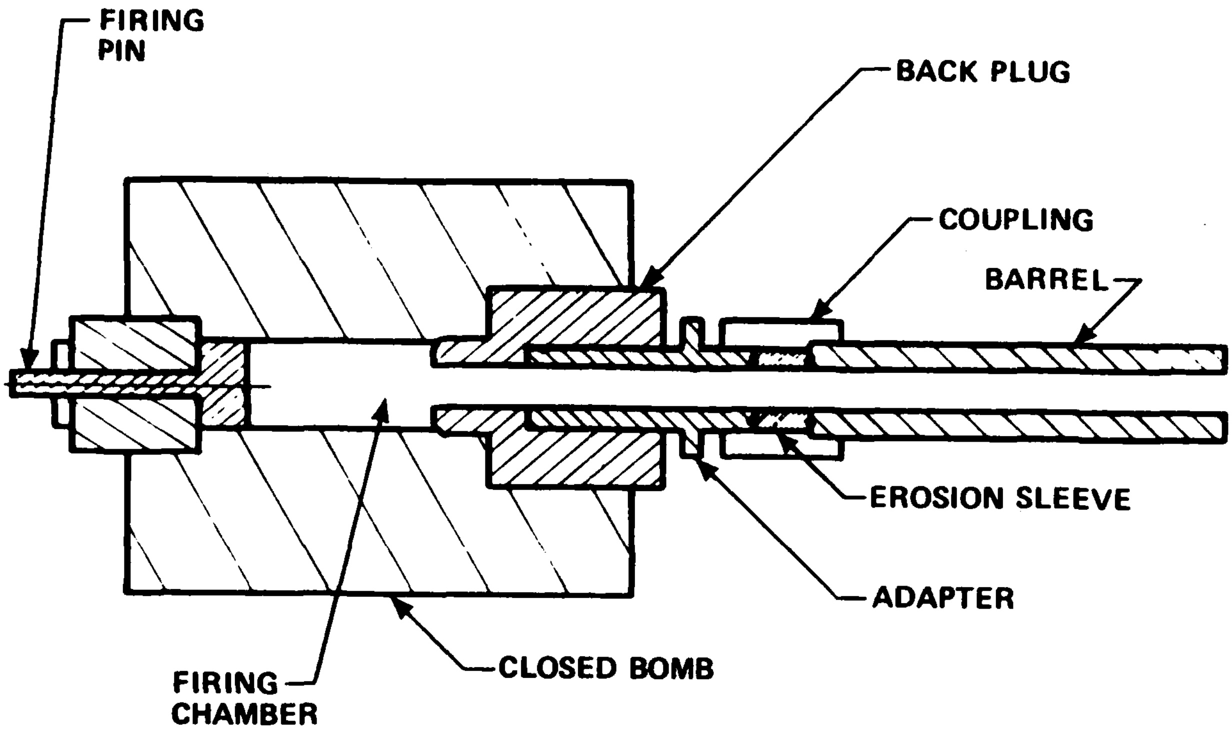

Figure 1. Sketch of erosion apparatus

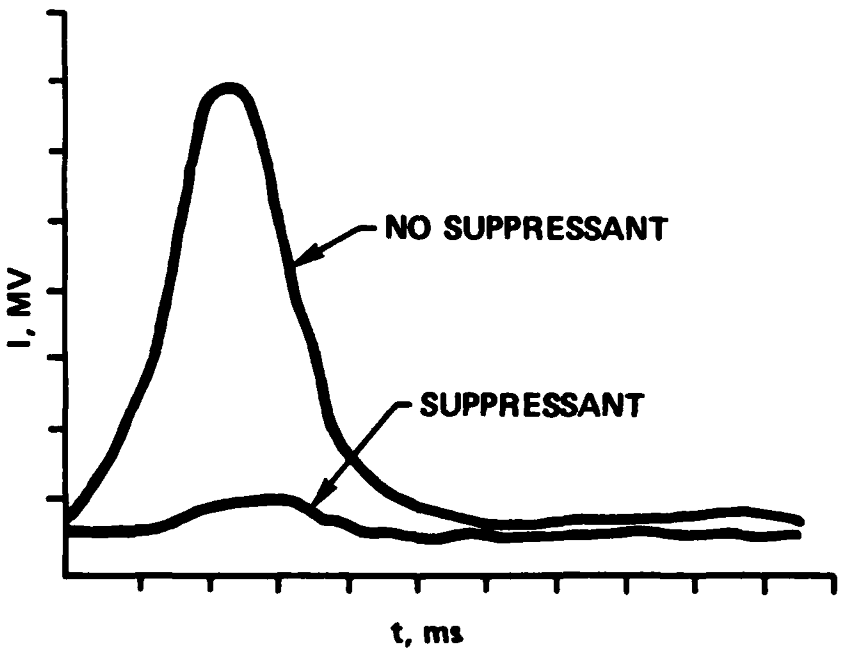

Figure 2. Light intensity versus time for typical unsuppressed and flash suppressed 50-g M30 propelling charges in ARRADCOM erosion tester

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